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Proposed Vision for Enhancing Technological, Pedagogical, and Content Knowledge (Tpack) Competency Integration Among Secondary School Biology Teachers in Riyadh City, Saudi Arabia

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ABSTRACT

Objective: The objective of this study was to assess and enhance the TPACK competencies of biology teachers in secondary schools, in line with the goals of Saudi Vision 2030. **Method:** Using a descriptive analytical approach, a total of 120 teachers based in Riyadh were asked to complete a questionnaire consisting of 52 items. The questionnaire covered 7 dimensions of TPACK and used a 5-point Likert scale. **Results:** The results showed a moderate level of proficiency overall. The dimensions of technological knowledge (TCK) and content knowledge (TPACK) had the highest mean scores of 3.64 and 3.61, respectively. This suggests an understanding of the connections between technology, content, and pedagogy. Technological Pedagogical Knowledge (TPK) had the lowest score (mean = 2.65), highlighting the importance of improving training on integrating technology tools with pedagogical methods. **Conclusion:** The study revealed that there was no discernible distinction between the experience and educational qualifications of teachers. The study highlights the importance of TPACK for biology teachers in effectively utilizing the internet and other technology to enhance information sharing with students through online platforms.

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Introduction

In the modern education system, it has become essential to incorporate information and communication technologies (ICT) into science subjects like biology. The growing demand for technological tools in science subjects has raised the need for instructors to acquire knowledge about ICT (Luo et al., 2023). Teachers must utilise technological tools to enhance their teaching effectiveness with students. In the same vein, Technological Pedagogical and Content Knowledge (TPACK) is rooted in the integration of technology, pedagogy, and content knowledge, which is essential for driving educational reforms in any country's academic sector (Fahadi & Khan, 2022).

The implementation of TPACK in the education sector has garnered the attention of policymakers, who are now focused on enhancing students' knowledge through the use of modern technology (Said et al., 2023). The framework of TPACK is built upon a comprehensive understanding of its integration into the wider context of technological and educational progress. Implementing TPACK enables teachers to anticipate upcoming advancements in the educational field, which are crucial for enhancing the quality of education (Nzaramyimana & Umugiraneza, 2023). In addition, the ever-evolving challenges and innovative solutions in the field of education enable educators to enhance their understanding and promote a culture of learning among students.

TPACK is crucial for biology education as it enables teachers to grasp the demands of contemporary education (Sarı & Keser, 2021). Teachers have the ability to foster a strong culture of technology and science in the classroom, which can greatly enhance students' understanding. Just like other fields, biology education also needs to adapt to the changing landscape by incorporating technology. By incorporating biology into various disciplines, students can gain a more comprehensive understanding of the world around them. This interdisciplinary approach equips them with the knowledge and skills needed to tackle the complex challenges of today (Chaipidech et al., 2021). Thus, it is crucial to incorporate the biological perspective with other disciplines in order to facilitate students' development.

Furthermore, the implementation of TPACK in the education sector enhances the dedication to fostering a favourable educational environment that respects traditional cultures (Huang et al., 2022). Through the implementation of TPACK, instructors can actively engage in a comprehensive process of material planning, lesson design, and detailed content analysis, enhancing the incorporation of values and skills. Thus, it is crucial for educators to adopt TPACK in order to enhance their understanding and elevate the quality of biology education. In addition, the progress in this field has the potential to enhance teaching methods and facilitate the implementation of new educational approaches.

It is crucial for teachers in the biology sector to implement TPACK. In addition, it is beneficial to update teaching methods to improve efficiency. Implementing TPACK can greatly benefit students as it allows them to access a variety of resources and learn through the integration of technology (An & Yang, 2021). It is essential for every country's education sector to strategically implement TPACK in order to develop competencies in students' working mechanisms. In addition, the relationship between teachers and students can be enhanced through the implementation of TPACK, as it improves educational practices.

In the past, there has been a lively discussion among experts about the significance of

TPACK in the field of education. The study conducted by Ning et al. (2022) highlights the importance of implementing TPACK and fostering a culture of innovation and knowledge sharing among students. In addition, Alamri and Awjah (2023) emphasised the importance of implementing TPACK in all schools, promoting equal access to enhanced student understanding and learning. In their study, Astuti et al. (2019) emphasised the importance of TPACK efficiency in enhancing the quality of teaching materials. This, in turn, plays a crucial role in imparting valuable knowledge to students. According to Wijayanto et al. (2023), there are challenges in the implementation of TPACK that can have a detrimental effect on students' knowledge and pose difficulties for teachers. In a recent study by Soler-Costa et al. (2021), it was found that there are certain areas where the application of TPACK frameworks and pedagogical knowledge falls short.

The studies highlight the importance of TPACK competencies in improving teaching methodologies. The article discusses the favourable attitudes of science teachers towards TPACK knowledge, as well as the difficulties encountered in putting it into practice. These valuable insights can greatly inform future educational strategies and professional development programmes focused on enhancing TPACK integration in science education, specifically in the field of biology. The study has following questions.

1. What is the extent of TPACK knowledge among secondary biology teachers in Riyadh?
2. Are there significant differences in TPACK competency levels based on educational qualifications and years of experience among secondary biology teachers in Riyadh?
3. What framework can be proposed to develop TPACK competencies among secondary biology teachers in Riyadh?

To achieve the objectives, the study has following objectives.

1. To evaluate the proficiency in TK, PK, CK, TPK, PCK, TCK, and TPACK among Riyadh's secondary school biology teachers.
2. To determine the presence of statistically significant disparities, at a significance threshold of 0.05, in TPACK competency levels based on educational background and experience among these educators.
3. To outline a strategy for advancing TPACK competencies within this group of teachers.

This study holds both theoretical and practical significance. Firstly, this study aims to investigate the level of TPACK competencies among secondary school biology teachers and explore strategies to enhance these competencies. Secondly, this study highlights the importance of enhancing the knowledge and skills of secondary school biology teachers in relation to Technological Pedagogical Content Knowledge (TPACK). Thirdly, the study contributes to Arabic libraries by providing additional research on the integrative knowledge of TPACK competencies among secondary school biology teachers, addressing the limited number of studies conducted in this specific context. Fourthly, the study aims to improve our understanding of the TPACK competencies possessed by secondary school biology teachers and the extent to which they possess them. Fifthly, the study highlights the importance of enhancing the knowledge and skills of secondary school biology teachers in TPACK and its application to improve teaching and learning outcomes and enhance student achievement. Stakeholders are urged to prioritise the development of these competencies.

The study offers recommendations and suggestions to improve the possession of TPACK competencies among secondary school biology teachers. Moreover, this research aids in the development of additional training courses and workshops focused on integrating TPACK dimensions into educational and teaching practices. The study's findings provide recommendations to improve TPACK competencies among secondary school biology teachers. The findings of recent research contribute to the development of training courses and workshops that focus on integrating TPACK dimensions into educational and teaching practices.

Literature Review

The study Schmid et al. (2021) was conducted on effectiveness of training program considering framework of TPACK for improvement in self-efficacy of teacher. It was determined that there was a clear difference between the mean score of teachers before and after execution of TPACK. Irmak and Yilmaz Tüzün (2019) examined pre-service biology teachers' TPACK knowledge. Results showed positive correlations between all TPACK domains, with the highest between pedagogical and technological knowledge. Pre-service teachers' pedagogical and technological knowledge was moderate, with a 3031-mean score.

In a study conducted by Aquino (2015), the focus was on evaluating the accessibility of e-learning competencies among teachers, with a specific emphasis on TPACK. There were no notable variations observed in terms of experience or job position. There was a significant availability of e-learning competencies. Recommendations were made to incorporate TPACK into teacher training and highlight its significance in e-learning research. Lachner et al. (2021) examined the integrated TPACK knowledge of social studies teachers from their perspective. Results revealed shortcomings that were linked to a dearth of specialised qualifications in social studies education. There were no notable variations in cognitive competencies and educational stage, whether considered individually or as a whole.

A study conducted by Astuti et al. (2019) investigated the TPACK proficiency of biology teachers in Indonesia, focusing on gender differences. The overall proficiency level was high. The level of technological knowledge was moderate. There was no significant gender-based differences in TPACK proficiency. Akturk and Ozturk (2019) examined the relationship between teachers' TPACK and students' self-efficacy and academic achievement in Konya and Ankara, Turkey. The study involved a sample of 78 teachers and 1597 students. The study employed a quantitative methodology and utilised the Children's Self-Efficacy Scale and TPACK surveys. The results revealed a significant positive relationship between teachers' TPACK knowledge, students' self-efficacy, and academic performance. This highlights the importance of academic self-efficacy as a key predictor of success.

Luik et al. (2018) examined Estonian pre-service teachers' TPACK attitudes. The study included 413 Tartu University students. They believed they could integrate technology despite their poor pedagogical knowledge. Gender affected perceptions, with men knowing more about technology and content. Older participants had various perspectives on technology but were more favourable about content. Yeh et al. (2015) examined TPACK proficiency and application in 40 Taiwanese secondary science instructors. The findings showed low proficiency and three application patterns: excessive technology use, transitional technology use, and planning and design. Technology-heavy teachers prioritise a student-cantered approach, while planning and design-focused teachers are proficient but may lack balance.

Lin et al. (2013) conducted a study on 222 science teachers in Singapore to examine their perceptions of TPACK. The results indicated that the teachers had positive attitudes towards all elements of TPACK, with a particularly strong correlation observed between Technological Pedagogical Content Knowledge (TPC) and other components of the framework. The studies conducted by Luik et al. (2018) and Yeh et al. (2015) both recognise the importance of the TPACK framework in improving educational outcomes. The studies demonstrate the positive influence of TPACK knowledge on teachers' effectiveness and students' academic performance, highlighting the significance of this framework in various educational contexts and subjects. The research gap identified through these comparisons lies in the nuanced understanding of how TPACK's implementation directly influences pedagogical strategies and student learning outcomes across different subjects beyond science and technology, particularly in the humanities and social sciences. Furthermore, there's a lack of longitudinal studies assessing the long-term impact of TPACK training on teaching practices and student achievements.

However, key points not addressed by previous studies include the differential impact of TPACK training based on teachers' initial competency levels, the role of school culture in facilitating or hindering the adoption of TPACK practices, and the integration of the TPACK framework in non-STEM subjects. The authors' academic contribution is the synthesis of these findings to highlight the universal applicability and potential benefits of the TPACK framework in modern education. This paper highlights the importance of studying TPACK's impact on teaching effectiveness and student learning in various educational disciplines. It emphasises the need for further research and application to fill gaps in knowledge and expand our understanding of TPACK's role.

Methodology

In order to accomplish the study objectives, the researcher utilised a descriptive-analytical methodology. The descriptive methodology prioritises the collection, classification, and tabulation of data to draw significant conclusions and formulate generalisations about the phenomenon under investigation. The study population included all female biology teachers at the secondary level in Riyadh City. The researcher randomly selected 120 teachers from this population to represent the study sample. The researcher analysed the frequencies and percentages of the study sample members based on their educational qualifications and years of experience.

Table 1

Distribution of Sample Members According to Academic Qualification.

	Academic Qualification	F	%
1	Bachelor's	96	80.0%
2	Master's	18	15.0%
3	Ph.D.	6	5.0%
Total		120	100.0%

Table 1 displays the distribution of sample participants according to their educational qualifications. The data reveals that 80% (96 members) of the 120 participants in the study hold a bachelor's degree, indicating a high level of education among the sample. Furthermore, 15% (18 members) possess a master's degree, while a smaller proportion, 5% (6 members), have obtained a Ph.D., indicating a decline in the presence of advanced academic qualifications among the group. The table summarises the educational composition of the sample, showing a strong preference for bachelor-level qualifications. Table 2 displays the distribution of experience levels among the sample members. It reveals that 9.2% have 1 to 5 years of experience, 63.3% have 5 to less than 10 years of experience, and 27.5% have more than 10 years of experience.

Table 2

Distribution of Sample Members According to Number of Years of Experience.

Sr No	Years of Experience	F	%
1	Less than 5 years	11	9.2%
2	From 5 to less than 10 years	76	63.3%
3	10 years and more	33	27.5%
	Total	120	100.0%

The researcher developed and improved a questionnaire to evaluate the integrative knowledge of TPACK competencies in secondary school biology teachers. This was done after conducting a thorough review of educational literature and prior research on the subject. The study instrument consisted of two main sections, which collected primary data on the respondents' educational backgrounds and years of professional experience in the first part. The second part of the study focused on the investigation's main aspects. It consisted of 52 statements divided into seven key domains. A five-point Likert scale ranging from "very weak" to "very strong" was used to assess the teachers' overall grasp of TPACK competencies.

The questionnaire was prepared, and its items were constructed. It was then reviewed by a panel of experts. The researcher subsequently participated in discussions regarding the feedback received. The questionnaire was modified based on suggestions from experts. This included deleting and rephrasing certain items. Over 80% of the experts agreed with these adjustments. The questionnaire was refined to enhance its face validity, resulting in a final version comprising 52 items distributed across seven primary axes. The internal consistency validity was assessed by calculating the Pearson correlation coefficient between the scores of each item and the total score of the corresponding axis, using responses from a sample of 30 participants (n = 30).

The results in Table 3 indicate that there were statistically significant correlations ($p < 0.01$) between the scores of individual statements and the total scores of their respective axes in the questionnaire. This suggests a high level of internal consistency and reliability. The correlations were robust across all axes: for "Technological Knowledge (TK)," coefficients ranged from.374* to.716**; for "Pedagogical Knowledge (PK)," from.430* to.787**; for "Content Knowledge (CK)," from.486** to.731**; for "Technological Pedagogical Knowledge (TPK)," from.421* to.758**; for "Pedagogical Content Knowledge (PCK)," from.562** to.697**; for "Technological Content Knowledge (TCK)," from.481** to.738**; and for "TPACK," from.476** to.727**. The results highlight the questionnaire's reliability in assessing the specific competencies. The results are displayed in Table 3.

Table 3

Pearson Correlations Between Item Scores and Axis Total Scores.

		The first axis: "Technological Knowledge TK"			
Paragraph number	**correlation coefficient**	**Paragraph number**	**correlation coefficient**	**Paragraph number**	**correlation coefficient**
1	.526**	5	.374*	9	.531**
2	.526**	6	.583**	10	.505**
3	.594**	7	.698**	11	.462*
4	.636**	8	.716**		
		The second axis: "Educational knowledge PK"			
12	.520**	15	.531**	18	.787**
13	.713**	16	.430*		
14	.523**	17	.535**		
		The third axis: "Content knowledge (CK)"			
19	.589**	22	.620**	25	.731**
20	.715**	23	.486**		
21	.534**	24	.548**		
		The fourth axis: "Technological Educational Knowledge (TPK)"			
26	.645**	29	.650**	32	.758**
27	.681**	30	.421*	33	.446*
28	.586**	31	.558**		
		The fifth axis: "Educational knowledge and content knowledge (PCK)"			
34	.623**	36	.562**	38	.616**
35	.697**	37	.666**		
		Sixth Axis: "Technological Knowledge and Content Knowledge TCK"			
39	.598**	42	.606**	45	.738**
40	.730**	43	.481**		
41	.583**	44	.584**		
		The seventh axis: "Educational technological knowledge and content knowledge (TPACK)"			
46	.602**	49	.621**	52	.658**
47	.727**	50	.476**		
48	.623**	51	.585**		

**Statistically significant at the 0.01 level.
*Statistically significant at the 0.05 level.

The convergent validity of the questionnaire axes was assessed by calculating the correlation coefficients between the total score of each axis and the overall total score of the questionnaire. The results in Table 4 indicate that there were strong and statistically significant correlations (ranging from .941** to .993**) between the questionnaire axes and the overall total score. All correlations were significant at the 0.01 level. The high coefficients indicate strong convergent validity for the questionnaire's axes, indicating consistent reflection of the measured constructs. The results are shown in Table 4.

Table 4

Correlation Coefficients Between the Total Score of Each Axis and The Overall Total Score of The Questionnaire Axes.

Sr No	The axes	Correlation coefficients
1	The first axis is "Technological Knowledge TK."	.952**
2	The second axis is "educational knowledge PK."	.953**
3	The third axis is "content knowledge (CK).	.993**
4	The fourth axis is "Technological Educational Knowledge (TPK)."	.956**
5	The fifth axis is "educational knowledge and content knowledge (PCK)."	.941**
6	Sixth Axis: "Technological Knowledge and Content Knowledge TCK"	.979**
7	The seventh axis is "educational technological knowledge and content knowledge (TPACK).	.984**

**Statistically significant at the 0.01 level.

Table 5 shows high reliability coefficients for the questionnaire axes, ranging from .988 to .991. The overall reliability coefficient for the questionnaire axes was .966. The reliability coefficients indicate the validity and reliability of the questionnaire and its results.

Table 5

Cronbach's Alpha Coefficients for Questionnaire Axes Reliability.

Sr No	The axes		Correlation coefficients
1	The first axis is "Technological Knowledge TK."	11	.991
2	The second axis is "educational knowledge PK."	7	.990
3	The third axis is "content knowledge (CK).	7	.988
4	The fourth axis is "Technological Educational Knowledge (TPK)."	8	.990
5	The fifth axis is "educational knowledge and content knowledge (PCK)."	5	.991
6	Sixth Axis: "Technological Knowledge and Content Knowledge TCK"	7	.988
7	The seventh axis is "educational technological knowledge and content knowledge (TPACK).	7	.988
	Total	52	.966

Statistical Methods

This study employed frequency and percentage analysis to describe the characteristics of the study participants and to assess their responses to the statements included in the study instrument. In addition, the study employed arithmetic means to rank the responses of the participants. Additionally, the study employed the Pearson correlation coefficient to establish the internal consistency validity of the research instrument. In addition, the study employed Cronbach's alpha coefficient to assess the reliability of the research instrument. The study employed the range equation to describe the arithmetic mean of responses to each statement. The study employed one-way analysis of variance (ANOVA) to assess statistical differences based on variables of academic qualification and years of experience.

Findings and Results

The data was analysed by calculating the arithmetic mean and standard deviation for each axis of the questionnaire. The axes were then arranged in descending order based on the arithmetic mean, as shown in Table 6. In order to investigate the research question, we computed the arithmetic means and standard deviations for each dimension of the questionnaire. Subsequently, we ranked these dimensions based on their mean scores. The findings, presented in Table 6, indicate a moderate level of integrative knowledge of Technological Pedagogical Content Knowledge (TPACK) among high school biology teachers. The survey yielded a mean score of 3.33, with a standard deviation of 0.315, suggesting minimal variability in respondents' views across the survey dimensions.

Table 6

Integrative Knowledge of TPACK Competencies in Secondary Biology Teachers.

Sr No	Axis	Arithmetic Mean	SD	Axis Order	Response Score
6	Sixth Axis: "Technological Knowledge and Content Knowledge TCK"	3.64	.670	1	High
7	The seventh axis is "educational technological knowledge and content knowledge (TPACK).	3.61	.879	2	High
3	The third axis is "content knowledge (CK).	3.53	.529	3	High
2	The second axis is "educational knowledge PK."	3.35	.535	4	Moderate
5	The fifth axis is "educational knowledge and content knowledge (PCK)."	3.32	.694	5	Moderate
1	The first axis is "Technological Knowledge TK."	3.29	.534	6	Moderate
4	The fourth axis is "Technological Educational Knowledge (TPK)."	2.65	.706	7	Moderate
	The total score of the questionnaire	3.33	.315	---	Moderate

Dimension six, "Technological Knowledge and Content Knowledge (TCK)," achieved the highest ranking with a mean score of 3.64 and a standard deviation of 0.670. It was followed by dimension seven, TPACK, with a mean of 3.61 and a standard deviation of 0.879. The third place was held by "Content Knowledge (CK)" with a mean of 3.53 and a standard deviation of 0.529. In fourth place was "Pedagogical Knowledge (PK)," with a mean of 3.35 and a standard deviation of 0.535. The fifth rank went to "Pedagogical and Content Knowledge (PCK)" with a mean of 3.32 and a standard deviation of 0.694. "Technological Knowledge (TK)" was sixth with a mean of 3.29 and a standard deviation of 0.534. Lastly, "Technological Pedagogical Knowledge (TPK)" was ranked at the bottom with a mean of 2.65 and a standard deviation of 0.706.

The significance of dimension six, "TCK," highlights the importance that high school biology teachers attach to incorporating technological knowledge in their teaching. The authors acknowledge the crucial role of technology in enabling innovative teaching approaches in the field of biology, especially in light of continuous advancements and discoveries. This recognition has significantly increased their motivation to improve their technological and content knowledge skills. The findings of this study differ from those of Oubibi et al. (2022), who identified a deficiency in the integrated knowledge of social studies teachers in relation to TPACK competencies. The insufficient training received by the sample high school biology teachers is attributed by the researcher as the reason for the lower ranking of the "Technological Pedagogical Knowledge (TPK)" dimension. The participants' limited training impeded their capacity to recognise and utilise the different types of knowledge necessary for effective teaching in a technology-enhanced learning setting. Therefore, this limitation has exacerbated the difficulties of using technology to support various teaching methods, resulting in its low ranking in the survey dimensions. The results align with the study conducted by O'Connor et al. (2023), which found a moderate level of technological knowledge (TK) proficiency among the participants.

The hypotheses postulated that there would be no statistically significant differences, at a significance level of 0.05, in the survey dimensions and overall score based on variables such as educational qualification and years of experience. A one-way ANOVA was conducted to determine the significance of differences in survey responses among the study sample based on educational qualification. The analysis results for the survey dimensions and overall score are presented in Table 7. The results from Table 7 indicate that there were no noteworthy differences in perceptions within the research sample when it comes to the various dimensions being studied. Specifically, there were no significant differences based on educational qualifications for the first dimension, Technological Knowledge (TK), as well as the second dimension, Pedagogical Knowledge (PK). Similarly, no significant differences were found for the third dimension, Content Knowledge (CK), and the fourth dimension, Technological Pedagogical Knowledge (TPK). Additionally, no significant differences were observed for the fifth dimension, Pedagogical and Content Knowledge (PCK), and the sixth dimension, Technological Knowledge and Content Knowledge (TCK). Lastly, no significant differences were identified for the seventh dimension, TPACK, based on qualifications. Overall, when considering all aspects of the survey, there are no notable variations based on the educational qualifications of the sample, as determined by statistical analysis at the 0.05 level.

Table 7

ANOVA Results for Survey Response Differences by Educational Qualification.

Axis	Sum of Squares		Degrees of Freedom	Mean Square	F	Significance Level
The first axis: "Technological Knowledge TK"	Between groups	.595	2	.298	1.041	.356
	Within groups	33.426	117	.286	---	
	the total	34.021	119	---	---	
The second axis: "Educational knowledge PK"	Between groups	.466	2	.233	.812	.447
	Within groups	33.615	117	.287	---	
	the total	34.081	119	---	---	
The third axis: "Content knowledge (CK)"	Between groups	.824	2	.412	1.483	.231
	Within groups	32.481	117	.278	---	
	the total	33.305	119	---	---	
The fourth axis: "Technological Educational Knowledge (TPK)"	Between groups	1.808	2	.904	1.837	.164
	Within groups	57.582	117	.492	---	
	the total	59.390	119	---	---	
The fifth axis: "Educational knowledge and content knowledge (PCK)"	Between groups	1.654	2	.827	1.738	.180
	Within groups	55.689	117	.476	---	
	the total	57.344	119	---	---	
Sixth Axis: "Technological Knowledge and Content Knowledge TCK"	Between groups	1.020	2	.510	1.138	.324
	Within groups	52.449	117	.448	---	
	the total	53.469	119	---	---	
The seventh axis: "Educational technological knowledge and content knowledge (TPACK)"	Between groups	1.773	2	.887	1.148	.321
	Within groups	90.322	117	.772	---	
	the total	92.095	119	---	---	
Total degree	Between groups	.073	2	.036	.362	.697
	Within groups	11.756	117	.100	---	
	the total	11.829	119	---	---	

In order to assess the significance of variations in the responses of the study sample to survey items, a one-way ANOVA was conducted, taking into account the variable of years of experience. The results of this analysis, pertaining to the survey dimensions and the overall score, are provided in Table 8 below. The results from Table 8 indicate that there were no significant differences observed at the 0.05 level across various dimensions, including Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Pedagogical and Content Knowledge (PCK), Technological Knowledge and Content Knowledge (TCK), and TPACK. Additionally, there were no significant differences found in the overall survey scores when considering the years of experience among the participants in the study. The consistency in responses indicates a collective understanding of TPACK competencies among high school biology teachers. This is likely a result of frequent interactions and the exchange of knowledge and experiences regarding TPACK. It ensures that despite differences in years of experience, their responses remain aligned. The findings align with a study conducted by Hossain et al. (2021), which similarly found no notable variations in the electronic education competencies of secondary school teachers, regardless of their years of experience.

Table 8

One-Way ANOVA Results: Response Variability by Experience Years Across Questionnaire Dimensions and Total Score.

The Axis		Sum of Squares	Degrees of Freedom	Mean Square	F	Significance Level
The first axis: "Technological Knowledge TK"	Between groups	.595	2	.298	1.041	.356
	Within groups	33.426	117	.286	---	
	the total	34.021	119	---	---	
The second axis: "Educational knowledge PK"	Between groups	.466	2	.233	.812	.447
	Within groups	33.615	117	.287	---	
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Total Degree	Between groups	.073	2	.036	.362	.697
	Within groups	11.756	117	.100	---	
	the total	11.829	119	---	---	

Discussion

The study's findings indicate that secondary biology teachers possess a moderate level of integrative knowledge when it comes to TPACK competencies. Specifically, they show a good understanding of "Technological Knowledge and Content Knowledge (TCK)" and TPACK. This observation is consistent with the findings presented in Astuti et al. (2019) study on the level of technological knowledge among biology teachers in Indonesia. In addition, the study findings challenge the results of Al-Shammari's (2020) research, which pointed out the shortcomings in the integrated knowledge of TPACK competencies among social studies teachers in Saudi Arabia. Nevertheless, the results align with the findings of Al-Otaibi's (2022) study, which indicated that there were no notable variations in the e-learning competencies of TPACK among secondary teachers based on their background variables. The researcher highlights the significance of TCK in biology education and its ability to support innovative teaching methods that align with Vision 2030 goals. The limitations in the dimensions of "Technological Pedagogical Knowledge (TPK)" highlight the importance of high-quality training programmes that specifically address the integration of technology knowledge with standard pedagogical strategies. In general, the study provides an important contribution to assessing the current TPACK proficiency levels among biology teachers in Saudi Arabia, while also highlighting specific areas that need to be strengthened.

Conclusion

The study found that high school biology teachers demonstrated a moderate level of integrative knowledge in TPACK competencies. The Technological Knowledge and Content Knowledge (TCK) dimension had the highest average score of 3.64, with a standard deviation of 0.670. TPACK, with an average score of 3.61 and a standard deviation of 0.879, closely trailed behind. Content knowledge (CK) ranked third with an average score of 3.53 and a standard deviation of 0.529. Pedagogical knowledge (PK) ranked fourth, with an average score of 3.35 and a standard deviation of 0.535. Pedagogical and Content Knowledge (PCK) ranked fifth with an average score of 3.32 and a standard deviation of 0.694. Technological knowledge (TK) had an average score of 3.29 and a standard deviation of 0.534. The lowest average score for Technological Pedagogical Knowledge (TPK) was 2.65, with a standard deviation of 0.706.

In conclusion, the research revealed that there was no difference in TPACK competency perceptions, despite variations in teachers' experience and qualifications. The findings indicate that biology teachers in Saudi Arabia are collaborating to adopt technology and make significant changes in their teaching practices. In Saudi Arabia, policymakers must empower teachers with the TPACK framework to enhance their expertise and foster a culture of innovation in order to meet the goals of Vision 2030.

Implications

This study contributes to the field of effective assessment frameworks in secondary school biology by evaluating the integrated TPACK competencies of teachers. The study also identifies strengths and limitations that can inform future models aimed at improving biology education standards. In addition, the understanding of collaborative cultures for enhancing TPACK is strengthened by the consistent findings among different demographic sub-groups. The findings highlight the importance of providing critical training in professional development programmes that integrate technological and pedagogical knowledge. This will equip teachers with advanced knowledge and skills to foster innovation, in line with Vision 2030. The findings also contribute to the creation of guidelines for administrators to foster communities of practice focused on enhancing collective TPACK proficiency through continuous knowledge sharing, in line with the evolving best practices for technology-enabled biology instruction.

Study Limitations

The study has several limitations. The study was limited to federal secondary schools in Riyadh city. Generalising the findings poses a challenge. The use of a self-reported questionnaire as the study instrument limits the measurement of teachers' TPACK proficiency due to individual subjectivity and perceptions, which may not accurately reflect their actual competency levels. Validation of the findings could be enhanced by including proficiency assessments conducted by experts. The analysis was limited to educational qualifications and years of experience when considering background factors. Examining potential variations in TPACK knowledge across different demographic variables could offer further insights. The study's cross-sectional design captures proficiency levels at a single point in time.

Longitudinal tracking can assess the development and progress of teachers' TPACK competencies during continuous professional development. The study mostly looks at numbers, using responses to a Likert scale questionnaire. It doesn't go into much detail about the difficulties and needs teachers have when it comes to improving integrated TPACK. Qualitative methods can provide more comprehensive information for determining training priorities. Future studies should follow specific directions. We should conduct additional studies across different educational regions and subjects within the Kingdom to compare the outcomes of this study with others. Furthermore, it is critical to investigate the efficacy of a training program that incorporates the TPACK framework in order to improve self-efficacy among high school biology teachers. A recommended approach is to explore teachers' perceptions of TPACK before and after their service.

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